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Positive affect facilitates task switching in the dimensional change card sort task: Implications for the shifting aspect of executive function

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Using the modified Dimensional Change Card Sort task, we examined the influence of positive affect on task switching by inspecting various markers for the costs, including restart cost, switch cost and mixing cost. Given that the executive-control processes that underlie switching performance—i.e., inhibition or shifting—are distinct from the component processes that underlie non-switching performance—i.e., stimulus evaluation, resource allocation or response execution—we hypothesised that if positive affect facilitates task switching via executive-control processes, rather than via component processes, positive affect would reduce both switch and restart costs, but not mixing cost, because both switch and restart costs rely on executive processes, while mixing cost imposes only minimal demands on executive processes. We found beneficial effects of positive affect on both restart and switch costs, but not on mixing costs. These results suggest that positive affect improves switching abilities via executive processes rather than via component processes.

Keywords: Positive affect; Dimensional change card sort (DCCS); Task switching; Switch cost; Mixing cost; Restart cost.

One of the most consistent and robust findings in the affect literature is that mild positive affect improves cognitive flexibility, which is the ability to shift attention among relevant ideas and to effectively adjust behaviour based on changing environmental demands (for a review, see Isen, 2008). For example, positive affect has been found to facilitate flexible and non-typical categorisation of neutral stimuli—including neutral person types—without simultaneous loss of typical categorisation; diverse and unusual (as well as usual) word associations to neutral words; flexible consideration of a choice set of products for purchase; flexible perspective-taking in interpersonal negotiation; decreased anchoring

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(i.e., more sufficient adjustment and responsiveness to information); greater integration of information in reasoning; and flexible control of attention (Isen, 2008). In light of the facilitating effects of positive affect on flexibility in thinking, the question arises whether positive affect would also facilitate flexibility in task switching.

Past research suggests that similar cognitive processes appear to underlie both cognitive flexibility and task-switching performance. For instance, the literature on task switching attributes significant response-time (RT) costs following a task switch to the time consumed by the control processes required for reconfiguration of the task set (Monsell, Sumner, & Waters, 2003). Likewise, the affect literature suggests that positive affect improves cognitive flexibility via controlled processes (Carpenter, Peters, Västfjäll, & Isen, 2013; Gray, 2001; Yang, Yang, & Isen, 2013). Similarly, the *flexibility* theory posits that the facilitating effects of positive affect on cognitive flexibility occur via changes in both *cognitive organisation*—i.e., how multiple aspects of stimuli or ideas are thought about, related to other ideas and organised in response to a current goal—and *cognitive elaboration*, which refers to a higher degree of mental effort that involves (1) integration and analysis of information, (2) active storage and retention of information and (3) flexible focus of attention (for discussion, see Isen, 2008, p. 550). These processes are further postulated to be related to the aspects of executive functions, which are the control mechanisms that modulate the operation of various cognitive processes such as shifting, updating, monitoring and inhibitory control (Miyake et al., 2000). Taken together, both theoretical and empirical studies suggest that positive affect would improve flexibility not only in thinking but also in task switching via controlled processes.

Dreisbach and Goschke (2004) were the first to demonstrate that positive affect promotes flexible switching of cognitive sets. Their study, however, focused specifically on the effect brief presentation of affective stimuli has on switch costs; therefore, any generalisation of their findings to a subjective experience of positive affect should be undertaken cautiously. Moreover, the study employed a task that was based on a cognitive set-switching paradigm in which participants performed a single categorisation task using one colour while ignoring a distractor in another colour that was presented simultaneously. Thus, their task differed slightly from a task-switching paradigm in which participants are required to rapidly switch between competing tasks based on a bivalent stimulus. Lastly, Dreisbach and Goschke were primarily concerned with switch cost. However, given that various types of costs in a task-switching paradigm have different origins and neural correlates (Philipp, Kalinich, Koch, & Schubotz, 2008; Rubin & Meiran, 2005), it is critical to examine the influence of positive affect in a more finely grained manner by inspecting various markers for cost type—i.e., switch cost, restart cost or mixing cost.

In this study, we examined two primary issues. First, we induced positive affect and sought to examine its effect on task-switching performance using a modified version of the Dimensional Change Card Sort task (DCCS; Frye, Zelazo, & Palfai, 1995), in which participants are presented with bivalent cards depicting familiar objects that differ on two dimensions such as colour and shape (e.g., blue trucks and red stars) and asked to sort cards on one dimension (e.g., shape: blue trucks with red trucks).[1] The sorting rules then change, and participants are instructed to sort the same test cards on the other dimension (e.g., colour: blue trucks with blue stars). This allows us to examine executive processes such as shifting, which is the ability to move back and forth among

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[1] The DCCS task has been widely employed to test young children in a developmental context. However, numerous studies using this task have revealed that switching difficulties can extend well into early adolescence (Morton, 2010) and young adulthood due to the increased RT required by the executive processes necessary to switch from one task to another (Diamond & Kirkham, 2005).

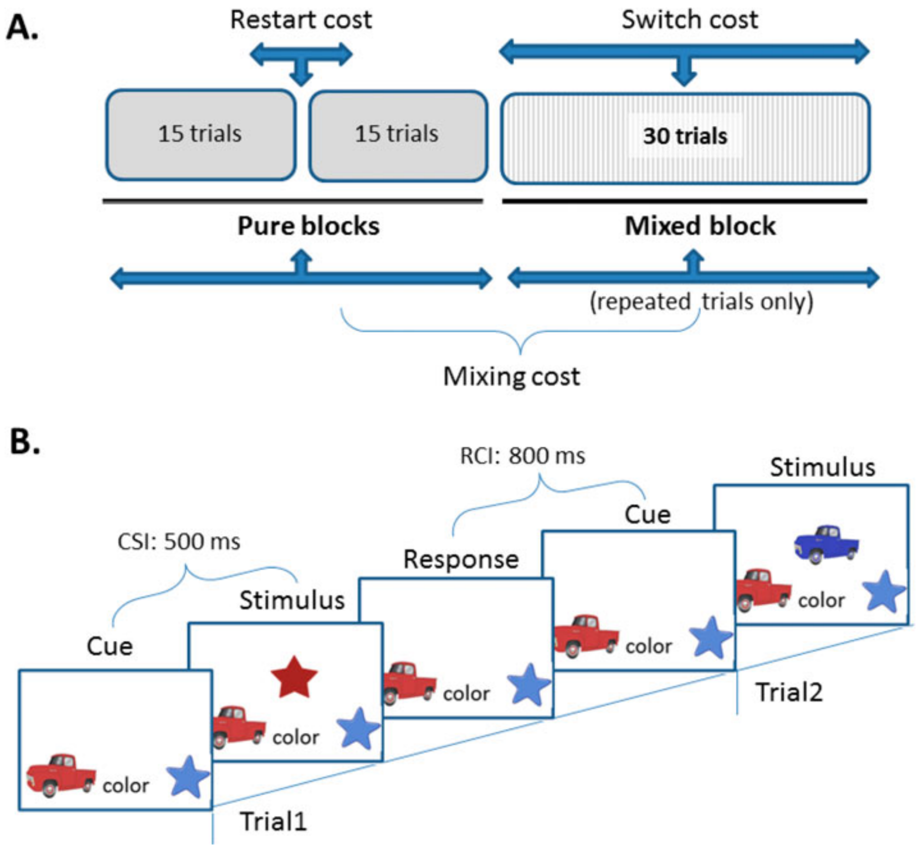

Figure 1. *The top panel (A) illustrates the main experimental procedure. Restart cost was calculated by subtracting the mean RTs of the last two trials of the first dimension (Block 1) from that of the first two trials of the second dimension (Block 2). Switch cost was calculated from trials within the mixed block by comparing the mean RT of task-repeat trials (P2) with that of task-switch trials (P1). Mixing costs were computed by comparing the mean RT of the two pure blocks—after discarding the first two trials of each block, which suffered from restart costs—with that of task-repeat trials in the mixed block. The bottom panel (B) is a schematic depiction of the Dimension Change Card Sort (DCCS) task used with adults in the study (adapted from Diamond & Kirkham, 2005). CSI, cue-stimulus interval; RCI, response-cue interval.*

multiple tasks (Rogers & Monsell, 1995), and inhibitory control, which is the ability to inhibit dominant, automatic or prepotent responses when necessary (Miyake et al., 2000).

Second, we aimed to decompose switching performance into three types of cost variables: restart, switch and mixing, each of which is acknowledged to involve somewhat different control processes (Rubin & Meiran, 2005). To this end, we included three blocks in the DCCS—two pure blocks of single-task trials and one block of intermixed task-switch and non-switch trials (Figure 1). The difference between mean RT for the last two trials in the first pure block and mean RT for the first two trials in the subsequent pure block is termed "restart cost" (Poljac, de Haan, & Van Galen, 2006). The mean RT difference between task-switch trials and task-repeat (i.e., non-switch) trials within the mixed block is termed "switch cost" (Rogers & Monsell, 1995). Lastly, the mean RT difference between task-repeat trials in the mixed block and corresponding trials in the pure blocks—in which no switch is made—is termed "mixing cost" (Koch, Prinz, & Allport, 2005; Rubin & Meiran, 2005).

A number of studies suggest that the executive-control processes employed in the task-switching paradigm can be functionally independent and dissociated. According to Rubin and Meiran (2005), these processes include either global control mechanisms (i.e., component processes)—which appear to underlie non-switch tasks—or specific control mechanisms (i.e., executive-control processes)—which are involved in switch tasks. Consistent with this view, the literature has documented empirical evidence of dissociations. For instance, Gopher (1996) found that instructions about a switch influence switching performance but do not affect non-switching performance. Rubinstein, Meyer, and Evans (2001) demonstrated that a warning cue influences non-switching trials without affecting switching trials. Cepeda, Cepeda, and Kramer (2000) observed that children with attention deficit hyperactivity disorder (ADHD) exhibit disproportionately large switch costs based on switch trials and normal costs based on non-switch trials. Taken together, this empirical evidence of dissociations suggests that the control processes that support switching trials are distinct, at least in part, from those that support non-switching trials.

In light of this, we hypothesised that if positive affect facilitates executive-control processes (i.e., inhibition control or shifting) more effectively than other component processes (i.e., stimulus evaluation, resource allocation or response execution), positive affect—as compared to neutral affect—would reduce both switch and restart costs because they are based on task-switch trials that appear to tap the specific control processes necessary for disengagement from one task and preparation for a subsequent task (Koch et al., 2005). In contrast, we hypothesised that positive affect does not moderate mixing cost, because it is based on non-switch trials that appear to involve processes that are distinguished from switching processes in general (Rubin & Meiran, 2005).

METHOD

Participants

Eighty-six undergraduates (males = 33, 18–23 years of age) from Cornell University participated in exchange for extra course credit. Data from two participants who had learned English only after the age of five years were excluded because of linguistic demands imposed by the Remote Associates Test (RAT) and Word Completion Task (WCT), two manipulation checks on induced mood. Half (n = 42) were assigned to the positive-affect condition and the other half (n = 42) to the neutral-affect condition, which served as a control group.

Design

We manipulated affect (positive, neutral) as a between-participant factor, and thus assigned participants randomly to either the positive-affect or neutral-affect condition. Preliminary analyses did not show any effects of gender or order-of-sorting rules (i.e., colour first or shape first), so these variables were not included in the reported analyses. Three types of costs (restart, switch and mixing) served as dependent variables.

Materials

Mood manipulation check

Induced affect was assessed by unobtrusive manipulation checks, including the RAT and WCT. Despite the assumed effectiveness of an explicit mood check that asks participants to indicate the degree of their current feeling states, such measures were inappropriate for our purposes because, given that positive affect was induced by an unexpected gift, following the gift with an obvious question about mood could dispel the induced feeling state by causing participants to mistrust the experimenter's intent in giving them the gift (Isen & Erez, 2007).

In the RAT, a person is required to think of a word that is related to each of three other words presented—for instance, "Cadet", "Capsule" and "Ship" (answer: Space). In all, 21 RAT items of moderate difficulty were selected from the normative data of Bowden and Jung-Beeman (2003). The WCT requires participants to complete a list of word fragments with missing letters. We expected that compared to neutral affect, positive affect would enhance performance on both the RAT and WCT for two reasons. First, the literature has consistently reported a strong relationship between mild positive affect and improved performance on the RAT and WCT, and second, both measures are related to cognitive abilities such as verbal fluency, association and insightful problem-solving, all of which have been shown to improve under positive affect (Isen & Erez, 2007).

DCCS

The DCCS was modelled after the one used by Diamond and Kirkham (2005). In the task, the target picture (either a blue truck or red star) appeared in the centre of the screen, and participants were asked to sort the target by a previously specified rule (Figure 1). Two reference pictures (a red truck and a blue star) remained visible at the bottom of the screen throughout the test, with the red truck at the bottom left and the blue star at the bottom right. Neither of the target pictures matched a reference picture on both colour and shape. The location of the reference pictures corresponded to the location of the response key to press to reduce memory load in the task. An explicit cue (colour or shape) appeared on every trial between the two reference pictures at the bottom of the screen, indicating the sorting criterion.

Procedure

Positive affect was induced by giving participants an unexpected gift—a small bag of candy that was attractively tied with a piece of yarn—as a token of appreciation for their participation. The gift was presented before testing began, but participants were asked to put the gift away with their books and take it with them when they left the lab. This was done to minimise potential demand characteristics by ensuring that participants would not eat the candy and associate it, during the session, with the purpose of the study. Participants in the neutral condition did not receive the gift and were unaware of its presence. We strove, however, to ensure equivalent levels of interaction between participants and the experimenter by following the same behavioural protocol (e.g., the same verbal expression of thanks). The RAT was then administered to assess the effectiveness of the induced affect as an implicit manipulation check.

Next, a computerised version of the DCCS was administered. The test consisted of three blocks: two pure blocks of a single sorting task (based on either colour or shape) and one mixed block of two tasks—i.e., both colour and shape tasks intermixed within the block. The order of the three blocks was fixed, with the two pure blocks administered prior to the mixed block, since the mixed block is perceived as being more difficult than the pure blocks, and performing different tasks of increasing difficulty is believed to be less disruptive of cognitive performance and induced affect (Yang et al., 2013). The two pure blocks consisted of 15 task-repeat trials each, and the mixed block of 30 trials that included both task-switch and task-repeat (i.e., non-switch) trials. In the mixed block, two sorting tasks alternated every two or three trials, resulting in 18 repetition trials [i.e., AA(A) or BB(B)], and 12 switch trials (e.g., AB or BA), with a task probabilistic ratio of roughly 1.5:1. This rendered task switching unpredictable.

Each trial began with a cue specifying the trial's sorting rule. When the cue was preceded by the target picture, the participant sorted the target picture by pressing a corresponding response key as accurately and quickly as possible, and RT in milliseconds was measured from the appearance of the target picture to the key press. Throughout all DCCS trials, the cue-to-stimulus interval (CSI) and the response-to-cue interval (RCI) were fixed to 500 ms and 800 ms, respectively. The order-of-sorting criteria between the pure blocks (i.e., colour first and shape second, or vice versa) and within the mixed block were counterbalanced across participants. After this, the WCT was administered as another mood check to ensure that induced mood remained effective until the end of the study. Upon completion of the study, a funnel questionnaire was administered to examine participants' awareness of research hypotheses, suspicions about the study, and, during task switching, choice of spontaneous strategies (i.e., focusing on the relevant rule or ignoring the irreverent rule).

RESULTS

Affect-manipulation check

An independent-samples *t*-test was performed on the RAT, which was administered immediately after affect induction. As hypothesised, participants in the positive-affect condition performed significantly better (M = 11.1, SD = 3.8) than those in the neutral-affect condition (M = 7.5, SD = 4.7), $t(82) = -3.57$, $p < .001$, Cohen's $d = -.079$. Consistently, another independent-samples *t*-test on the WCT—which was administered after the DCCS task—revealed that the positive-affect group outperformed the neutral-affect group, $t(82) = -2.02$, $p = .046$, Cohen's $d = -.044$. Together, these results demonstrate that the method used to induce positive affect was effective and that participants in the positive-affect condition felt more positive throughout the test than those in the control condition.

Performance costs

We present separate analyses of RT data for each type of performance cost below. Only correct trials were included; the rare RTs that were either more than 2.5 standard deviations above the mean or less than 200 ms were discarded (4% of total trials), which is a typical practice in the literature. Error rates were not further analysed, because they were consistently low; did not correlate with RTs, $r(84) = .033$, $p > .76$; and showed no difference between the two affect conditions, $t(82) = .7$, $p > .5$.

Restart cost

Using Diamond and Kirkham's method (2005), restart cost—which refers to the initial slowing after the switch to a different sorting dimension—was computed from the two pure blocks by comparing the average RT of the last two trials in the first dimension (Block 1) with that of the first two trials in the second dimension (Block 2). Analyses using different intervals of either one or three trials immediately before and after the switch did not change the general data pattern, and thus were not reported.

RT data were submitted to a mixed-factor analysis of variance (ANOVA) with affect (positive, neutral) as a between-participant factor and task-restarting (last two trials in Block 1, first two trials in Block 2) as a within-participant factor. Consistent with Diamond and Kirkham (2005), we found the main effect of task-restarting, indicating significantly elevated RTs when switching from the first to the second dimension, $F(1, 78) = 7.34$, $p = .008$, $\eta^2 = .09$ (Figure 2a).[2] This main effect interacted with affect, suggesting that positive affect significantly modulated restart costs, $F(1, 78) = 3.8$, $p = .05$, $\eta^2 = .04$. Planned comparisons revealed that restart costs were eliminated in the positive-affect condition, $p > .59$, but not in the neutral-affect condition, $t(39) = -3.3$, $p < .01$, Cohen's $d = -1.05$. This suggests that compared to neutral affect, positive affect enhances switching efficiency as reflected in restart costs.

Switch cost

Switch cost refers to RT difference between task-switch trials and task-repeat trials within the mixed block (Rogers & Monsell, 1995). Switch cost was analysed in the mixed block only as recommended in the recent literature, because pure blocks differ from mixed blocks in terms of working-memory demands, division of attention between perceptual dimensions, degree of arousal and effort and so on (Rubin & Meiran, 2005). The first two trials in the mixed block were

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[2] Note that the degree of freedom for restart costs differs from that of either switch or mixing costs. The loss of degree of freedom for restart costs occurred when trials (i.e., the last two or first two trials of pure blocks) that were used for the calculation of restart costs were discarded due either to errors or RT trimming, which was done for each individual, using individuals' means and SDs within each of the three blocks.

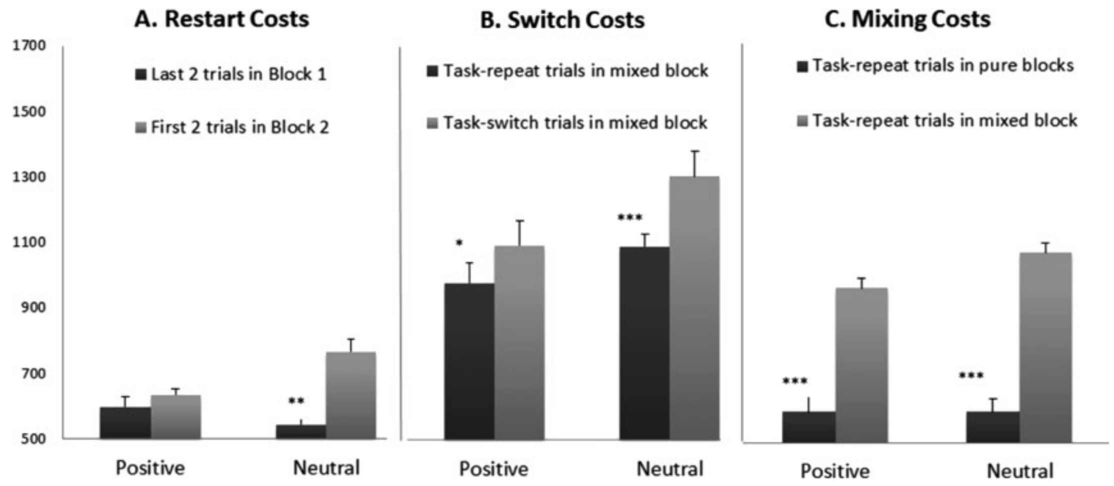

Figure 2. *Panel A shows restart cost as a function of induced affect. Restart cost was based on RT difference when switching from the first sorting dimension in Block 1 to the second sorting dimension in Block 2. Panel B shows switch cost based on RT difference between task-repeat and task-switch trials within the mixed block (Block 3). Panel C shows mixing cost based on RT difference between task-repeat trials in pure blocks and those in the mixed block.*

excluded because they were known to suffer from a form of restart cost that is typically present immediately following a task switch. Each trial in the mixed block was defined relative to its position: P1 (Position 1 = switch trial), P2 (Position 2 = first-repeat trial) and P3 (Position 3 = second-repeat trial). Because preliminary analyses showed minimal drops in RT between P2 and P3, we combined them as P2 and calculated switch cost by comparing task-switch trials (P1) with task-repeat trials (P2 and P3 combined).

RT data were submitted to a mixed-factor ANOVA with affect (positive, neutral) as a between-participant factor and task-switching (P1, P2) as a within-participant factor (Figure 2b). Switch costs were found, $F(1, 82) = 45.8$, $p < .001$, $\eta^2 = .66$, with significantly slower RTs on P1 (task-switch trials) than on P2 (task-repeat trials). A significant affect × task-switching interaction suggests that positive affect significantly modulated switch costs, $F(1, 82) = 4.7$, $p = .03$, $\eta^2 = .033$, with attenuated switch costs in the positive-affect group ($M_{\mathrm{P1-P2}} = 114$ ms) compared to the neutral-affect group ($M_{\mathrm{P1-P2}} = 214$ ms). Planned comparisons revealed that the group difference was caused by the positive-affect group's faster RTs on switch trials (P1; $M_{\mathrm{positive}} = 1088$ ms, $M_{\mathrm{neutral}} = 1299$ ms), $t(82) = 1.98$, $p = .05$. The two groups, however, did not differ on task-repeat switch trials (P2; $M_{\mathrm{positive}} = 975$ ms, $M_{\mathrm{neutral}} = 1085$ ms), $p > .2$. Consistent with results for restart cost, this suggests that positive affect enhances task switching, which appears to tap executive-control processes.

Mixing cost

Mixing cost refers to impaired performance on task-repeat trials in the mixed block compared to performance on task-repeat trials in pure blocks, in which no switch is made (e.g., Koch et al., 2005). Mixing costs were computed by comparing mean RTs of task-repeat trials in the two pure blocks with those of task-repeat trials in the mixed block. Note that the first two trials of each block were excluded due to restart cost. RT data were submitted to a mixed-factor ANOVA with affect (positive, neutral) and task-mixing (task-repeat trials in pure blocks, task-repeat trials in the mixed block). Mixing costs were significant (Figure 2c), with poorer performance in the mixed block

(M = 1032 ms) than in the pure blocks (M = 601 ms), $F(1, 82) = 131$, $p < .001$, $\eta^2 = 1.6$. This effect, however, did not interact with affect, $F(1, 82) = 2.13$, $p = .149$, indicating that positive affect did not modulate mixing cost, which appears to impose minimal demands on executive processes.

In summary, compared to neutral affect, positive affect significantly enhanced switching efficiency—as evidenced by restart and switch costs—but it did not modulate mixing cost.

Motivational effects

We investigated whether the observed effects of positive affect can be attributed to motivational factors. First, we examined RT to index any group differences in effort. A series of t-tests, however, showed no difference in the overall RT, $t(82) = .94$, $p = .35$, or averaged RTs in Block 1, $t(82) = -.32$, $p = .75$; Block 2, $t(82) = .55$, $p = .59$; or the mixed block, $t(82) = 1.6$, $p = .11$. We also determined whether the affect groups differed in RT on all trials that were used to compute various performance costs (Figure 1). Again, the two affect groups did not significantly differ in averaged RTs for trials involved in computing restart costs, $t(78) = .41$, $p = .53$; switch costs, $t(82) = 1.69$, $p = .095$; or mixing costs, $t(82) = .92$, $p = .34$, suggesting that the effect of positive affect cannot be attributed to the positive-affect group's seemingly faster responses.

Second, given the potential link between motivation and strategic orientation, we examined the funnel questionnaire to determine whether the two groups differed based on the spontaneous strategies they adopted. The chi-square test showed that the two affect groups did not differ in terms of strategies that involved either heightened focus on the currently relevant cue, $\chi^2(1) = 1.9$, $p = .16$, or intentional ignorance of the irrelevant cue, $\chi^2(1) = 2.4$, $p = .12$. We also created a variable that combines the two strategies. This variable coded the participant into one of three groups: those who used neither of the two strategies (coded as 0), either one of the two strategies (coded as 1) or both strategies (coded as 2). Despite the trend towards the positive-affect group's use of both strategies, the chi-square test was still consistent with our previous result, $\chi^2(2) = 4.35$, $p = .114$, indicating no significant association between induced affect and choice of spontaneous strategies.

We also conducted simple moderation analyses based on regression coefficients to examine choice of strategy as a moderator. When a series of simple moderation models were performed using a macro process generated by Hayes (2012), we found that positive affect emerged as a significant predictor for both restart and switch costs, but not for mixing costs. However, neither of the two strategies (i.e., heightened focus on the relevant cue or intentional ignorance of the irrelevant rule) significantly moderated the effect of positive affect on restart costs (ps > .11), switch costs (ps > .31) or mixing costs (ps > .79).

Third, we considered the possibility that giving an unexpected gift (i.e., a small bag of hard candies) could motivate participants in the positive-affect group to behave in the way they assumed the experimenter wanted them to. In view of this potential influence of demand characteristics, we examined our funnel questionnaire, which asked participants to guess the study's purpose and to report any suspicions about the study. The majority of participants (95.3%) in the positive-affect condition, however, had no ideas about the purpose of the gift, and even those who reported being suspicious of the gift failed to associate it with the study's hypothesis. Moreover, in view of the absence of explicit incentives or rewards associated with task performance, it is less likely that extrinsic motivation—which is typically driven by external rewards—moderated the effect of positive affect on performance costs. Taken together, there was not enough evidence to infer the influence of motivational differences.

GENERAL DISCUSSION

We found that positive affect had a beneficial effect on restart and switch costs, but not on mixing costs. This suggests that positive affect facilitates effective use of the control processes necessary to rapidly switch to a relevant task goal while simultaneously inhibiting an irrelevant task goal. It is also notable that the effect of positive affect was selective; it did not influence mixing costs calculated from non-switch trials, presumably because they impose fewer demands on executive processes. Given the view that the cognitive processes that underlie mixing cost may be different from those underlying either restart or switch costs (Cepeda et al., 2000; Koch et al., 2005; Rubin & Meiran, 2005), this evidence of dissociation implies that the main locus of positive affect's facilitating effects would likely lie in controlled abilities, such as those required to flexibly shift between tasks, override the tendency to produce an overlearned response or deal with potential proactive interference caused by bivalent stimuli, as opposed to component processes, such as simple abilities to *retain* multiple-task rules, evaluate perceptual stimulus or allocate resources. In any event, given that switching and inhibition functions are central to DCCS switch trials, our results point to improved flexibility in executive processes as the primary factor that explains the observed affect-related changes in restart and switch costs.

Our findings replicate and substantiate the observed link between positive affect and switching flexibility (Dreisbach & Goschke, 2004), by delineating the effect of positive affect on various types of switching variables. Our finding is also consistent with Isen's (2008) flexibility theory, which posits that positive affect facilitates flexible and careful cognitive processing through changes in cognitive organisation and cognitive elaboration. The neuropsychological theory of positive affect is also compatible with our findings, as it postulates that positive affect improves executive processes through the release of dopamine into the frontal regions of the brain (Ashby, Isen, & Turken, 1999). Lastly, Fredrickson's broaden-and-build theory (2001) is compatible with our findings, to the extent that her theory conceptualises positive emotions as being linked to flexibility in attention control (since people perceive broadly and build on that).

Our findings are not readily explained, however, by the affect-as-information theory, which posits that positive affect signals an absence of problems in the environment, resulting in heuristic rather than systematic processing strategies (Schwarz, 2002). This theory predicts that positive affect will impair switching performance, because controlled processes are impaired under positive affect. These ideas are not supported by our findings. It should be noted, however, that the discrepancy may be attributable in part to differences in design and implementation, such as the nature of the task (fun or dull) or the motivational intensity of induced positive affect (Gable & Harmon-Jones, 2008).

Cue-priming effects

Given that the DCCS is based on a 1:1 cue-task mapping (one cue per task) in which task switch and cue switch always co-occur, it is difficult to determine the relative contributions of task switching and cue switching to performance costs (for a review, see Logan & Bundesen, 2003). In contrast, several researchers who employed an explicit task-cueing procedure based on 2:1 cue-task mapping (two cues per task) have claimed that task switching can be triggered not only by executive control but also by basic cue-priming processes that underlie cue switching. A recent study, however, suggests that differences in switch costs calculated from tasks with either 1:1 or 2:1 mapping are small and non-significant in most analyses (Schneider & Logan, 2011). Although it is still controversial whether switch costs based on 1:1 mapping would solely be attributed to cue priming but not to executive control (for a review, see Altmann, 2006; Altmann & Gray, 2008), we acknowledge that the locus of the observed mood affect should be considered in light of both cognitive control (which underlies task switching) and basic cue-priming processes.[3] Below, we

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[3] We thank the anonymous reviewer for raising this issue.

present some reasons to believe that our observed effect of positive affect is attributable to cognitive control rather than to basic cue-priming processes.

First, it is notable that the DCCS is a widely used measure of executive function (for a review, see Zelazo, 2006), because successful performance on the DCCS requires more endogenous control than exogenous control. For example, a typical explicit-cueing paradigm requires the subject to judge single digits by either magnitude (greater or less than 5) or parity (odd or even), whereas the DCCS requires not only judgement about a bivalent stimuli (i.e., in terms of either colour or shape) but also use of an ability (i.e., inhibitory control) to match the target stimulus to a model picture that embodies conflict with the correct response. In support of this, recent brain-imaging studies suggest that the DCCS implicates executive processes. For example, Waxer and Morton (2011), using event-related potentials (ERPs), demonstrated that ERPs time-locked to the instruction cue revealed a late frontal negativity whose amplitude was greater for switch trials relative to repeat trials and was associated with the magnitude of the behavioural switch cost (p. 3267), indicating that the DCCS taps executive processes.

Second, it is noteworthy that among a number of procedural differences between typical task-cueing paradigms and the DCCS, the former usually employ several hundreds of trials, ranging between 320 and 960 (e.g., Logan & Bundesen, 2003), whereas the DCCS requires far fewer trials, thereby reducing the potential effects of practice—for instance, 80 trials in the adult version of the DCCS used by Diamond and Kirkham (2005). Given this, it is likely that the task-cueing procedure is subject to the influence of repetition priming, which is prone to become established through a greater number of trials. By contrast, the DCCS is less likely to rely on such priming, as performance with limited practice tends to require the ability to engage controlled processes.

Third, if the observed mood effect is attributable to cue-encoding benefits, we argue that such benefits should be manifested by well-strategised use of the cue. Thus, we examined whether the two affect groups differed in terms of cue-focused strategies, as assessed by the dichotomous items on the funnel questionnaire. The chi-square test, however, revealed that the two affect groups did not differ in choice of strategies involving heightened focus on the currently relevant cue, $\chi^2(1) = 1.9$, $p = .16$, or intentional ignorance of the currently irrelevant cue, $\chi^2(1) = 2.4$, $p = .12$. These results suggest that the two mood groups did not differ in use of the cue, which could lead to cue-encoding benefits.

Lastly, although the DCCS does not allow us to accurately determine the influence of positive affect on the cue-priming processes that underlie cue switching, we examined whether there was a systematic influence of positive affect on the temporal pattern of RT facilitations (i.e., RT drops over time) on task-repeat (non-switch) trials within the pure and mixed blocks. Given that cue-priming effects operate when cue-encoding benefits are established through the same cues that are repeatedly presented, RT facilitation on task-repeat trials can be used as an index of basic priming effects (e.g., Arrington, Logan, & Schneider, 2007). Accordingly, we first examined the influence of cue priming in the pure blocks by breaking trials of each pure block into three bins spanning five trials each (Bin 1, trials 1–5; Bin 2, trials 6–10; Bin 3, trials 11–15). When RT data were submitted to a 2 (order of pure blocks: first, second) × 2 (affect: positive, neutral) × 3 (Bin: first, second, third) mixed-factor ANOVA with affect as the only between-participant variable, we found main effects of Order and Bin and an interaction between Order and Bin. These effects indicate that averaged RT was faster for the second pure block than the first pure block, $F(1, 76) = 48.9$, $p < .001$; averaged RT of Bin 1 was slower than the other bins, $F(2, 152) = 96.5$, $p < .001$; and the significant RT drop from Bin1 relative to both Bin 2 and Bin 3 was more pronounced in the first pure block than in the second pure block. If positive affect exerted a different influence on cue priming, we would expect to find interaction effects with affect. None of the interactions involving affect, however, were significant. This suggests that both positive and neutral-affect groups were under similar levels of priming influence in the pure blocks.

Next, the cue-priming effect in the mixed block was approximated by examining RT facilitation across four different clusters of trials in which the same task cue as the preceding one appeared repeatedly in a row [i.e., first-repeat (P2) and second-repeat (P3) trials]. When RT data were submitted to a 2 (affect) × 2 (cue-repetition: P2, P3) × 4 (clusters: C_1, C_2, C_3, C_4) mixed-factor ANOVA, a significant three-way (affect × cue-repetition × clusters) interaction was found, $F(3, 141) = 3.06$, $p = .03$. Additional follow-up analyses revealed significant two-way (affect × cue-repetition) interactions in the first two clusters (C1 and C2), but not in the last two clusters (C3 and C4), indicating that affect modulated cue priming only in the first half of the mixed block. Further analysis, however, revealed that positive affect significantly facilitated RT between P2 and P3 in the first cluster, $t(66) = 2.94$, $p = .004$, whereas it significantly impeded RT between P2 and P3 in the second cluster, $t(75) = -2.3$, $p = .02$, suggesting that positive affect did not consistently modulate cue priming in the mixed block (Note that because P2 and P3 were yoked to calculate RT facilitation, the elimination of either one of those task-repeat trials—due to errors or RT trimming—resulted in different degrees of freedom for each cluster).

In addition, a 2 (affect) × 2 (task switching; task-switch trials, task-repeat trials) analysis of covariance (ANCOVA) was performed with cue priming (i.e., mean RT facilitations between task-repeat trials across all clusters) as a covariate. We found that cue priming did not significantly influence RTs in the mixed block, $F(1, 81) = .08$, $p = .78$; neither did it interact with task switching, $F(1, 81) = .32$, $p = .57$. Moreover, the effect of positive affect on switch costs was still substantial, even after controlling for the effect of cue priming as a covariate, $F(1, 81) = 3.44$, $p = .06$, indicating that the effect of cue priming was not associated with switch costs. Taken together, these results suggest that our finding regarding the effect of positive affect on task switching is attributable less to cue priming than to executive processing.

CONCLUSION

In summary, our results demonstrate that mild positive affect alleviates difficulty in disengaging from one task and switching to another via improved controlled processes of executive function. The possibility that the difference between the groups' performance was caused by changes in memory processing is not plausible, because response icons remained visible on-screen throughout the testing to minimise maintenance demands on working memory and to control for individual differences in working-memory capacity. Moreover, the possibility that similar cognitive abilities underlie both the RAT and task switching—which jeopardises the independence of the mood check from the DCCS—is less likely. The literature suggests that performance on the RAT is negatively related to the attentional-control abilities at the core of task-switching performance, because lowered attentional control facilitates a transition from a goal-directed behaviour to a more associative and creative mode (for a review, see Wiley & Jarosz, 2012). Thus, if the same and unitary attention-control process underlies both the RAT and the DCCS, enhanced performance on the RAT should be associated with impaired task switching in the DCCS. Our findings, however, markedly contrast to this hypothesis. Given the view that executive processes are multifaceted (e.g., Miyake et al., 2000), our findings suggest that different executive processes, although not mutually exclusive, may be associated with the RAT (e.g., attentional control) and the DCCS (e.g., shifting and inhibition control).

It is notable that the unexpected-gift paradigm, which was used to induce positive affect in the study, may implicate motivational mechanisms at the origin of control tasks. While there was a lack of evidence (i.e., overall RT, extrinsic motivation or demand characteristics), at least in our study, to infer that motivation modulated the effect of positive affect, our findings warrant future studies to delineate how motivation interacts with positive affect to influence our cognition and behaviour. Additionally, future studies should examine the scope and limits of affect-related changes in task switching to identify underlying processes and shed additional light on the relation between positive affect and various switching abilities. The specific controlled processes—e.g., attentional shifting, inhibition control, monitoring, cue priming or updating—that underlie a facilitating effect of positive affect on task switching should also be addressed. Since task switching is regarded as a shifting aspect of executive function—which is implicated in the performance of a wide-ranging group of cognitive and social processes—our finding that positive affect improves task-switching performance via executive processes means that this affective state has the potential to improve a multitude of social and non-social processes in everyday functioning.

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